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THE IN-SITU RECOVERY OF BITUMEN FROM OIL SANDS: PART 1: DEVELOPMENT OF A LABORATORY-SCALE TEST PROCEDURE AND PRELIMINARY RESULTS USING STEAM

E.C. McCOLGAN, J.L. MARGESON AND B.I. PARSONS

NOVEMBER 1983

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MICROMEDIA

MAY 18 1984

21 pp

ENERGY RESEARCH PROGRAM
ENERGY RESEARCH LABORATORIES
Report ERP/ERL 82-33 (TR)

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by

E.C. McCOLGAN*, J.L. MARGESON,** AND B.I. PARSONS***

ABSTRACT

The results of a preliminary study to model the in-situ recovery of bitumen from oil sand using steam are presented. Three different experimental arrangements were tested. In each case a cylindrical cell was manually packed with medium grade Athabasca oil sand and then mounted vertically. In the first arrangement the cell was heated at atmospheric pressure with nitrogen or nitrogen-steam flowing from top to bottom to see if the bitumen could be made to flow by gravity drainage or gas entrainment; no more than 5% of the initial bitumen-in-place was recovered. In the second arrangement, an "octopus" which allowed injection at the top and bottom and at various locations along the length of the cell was used. Two experiments in which hot water was injected showed recoveries of about 18% while those at steam temperatures were less than 3%. In the third arrangement a pressure vessel was used. The cell was heated to 245°C which resulted in a steam pressure of 3.4 MPa (500 psi). After the system reached steady-state a valve was opened to collect products. When the product was collected from the bottom, less than 4% of the bitumen was recovered; when it was collected through the top, 37% of the bitumen was separated from the oil sand.

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RECUPERATION IN SITU DU BITUME DES SABLES BITUMINEUX: PARTIE 1: MISE AU POINT D'UNE METHODE D'ESSAIS EN LABORATOIRE ET OBTENTION DE RESULTATS PRELIMINAIRES AVEC DE LA VAPEUR

par

E.C. McCOLGAN*, J.L. MARGESON,** AND B.I. PARSONS***

RESUME

On présente les résultats d'une étude préliminaire visant à élaborer un modèle simulant la récupération in situ du bitume des sables bitumineux. On a fait l'essai de trois protocoles expérimentaux différents. Dans chaque cas, on remplissait à la main une cellule cylindrique d'un sable bitumineux de qualité moyenne provenant de l'Athabasca. Dans le premier protocole, on chauffait la cellule à la pression atmosphérique en faisant circuler, du haut vers le bas, de l'azote ou un mélange d'azote et de vapeur, pour tenter de faire s'écouler le bitume par gravité ou par entraînement avec le gaz; cette méthode a permis de récupérer au maximum 5 p. cent du bitume initial. Dans le deuxième protocole, on a utilisé un système d'injections multiples à la partie supérieure, à la partie inférieure et à divers endroits le long de la paroi de la cellule. Le taux de récupération était de 18 p. cent lors de deux expériences comportant l'injection d'eau chaude, mais il était inférieur à 3 p. cent aux températures de la vapeur. Dans le troisième protocole, on a utilisé un récipient sous pression. On chauffait la cellule à 245°C, ce qui élevait la pression à 3,4 MPa (500 lb/po^2). Une fois le système à équilibre, on ouvrait une soupape pour récupérer les produits. Le taux de récupération était de moins de 4 p. cent dans le cas du produit prélevé à la partie inférieure, et de 37 p. cent dans le cas du produit provenant de la partie supérieure.

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INTRODUCTION

This report and others to follow in this series, examines the in-situ recovery of bitumen from oil sands using steam injection. The properties of the principal Canadian oil sands and heavy oil deposits are summarized in Table 1. These are highly viscous hydrocarbon materials at reservoir temperatures. Primary production is not possible (or is relatively small) and water displacement or gas drive methods of production are ineffective, or at best only marginally effective, in most cases. The success of the thermal methods for the production of such oils and bitumens is generally attributed to the large viscosity reduction brought about by increasing the temperature several hundred degrees. The dramatic effect of a two hundred degree change in temperature on the viscosity is shown in Fig. 1. Mechanistically, however, there is evidence to indicate that steam and hot water bring about larger recoveries than would be anticipated solely on the basis of lowered viscosity. The long range objective of this program of study is to establish the principal steps involved in the mechanism of in-situ production and the part that steam and/or additives (or naturally occurring substances in the formation) play in the separation and movement of bitumen.

BACKGROUND

The most frequently used thermal recovery method involves the injection of steam into the reservoir. Steam injection processes fall into two groups, cyclic steam stimulation and steam drive. Cyclic steam stimulation involves stimulation and production from a single well. High temperature, high pressure steam is injected to pressurize the reservoir. The injection period is typically one to five weeks after which the well is shut in to allow the reservoir pressures and temperatures to stabilize. This "soak" period is followed by a production period during which the bitumen which has been rendered sufficiently mobile flows to the well bore. The production rate is relatively high initially but declines slowly over 3 to 10 months. The entire process is then repeated until it is no longer profitable.

In steamflooding or steam drive, steam is pumped down one well to mobilize the bitumen and drive it toward a producer well. As the steam progressively heats the reservoir, the leading edge of the steam front generally condenses in the formation. In effect, during a steamflood, heated bitumen is displaced towards a production well by hot water and then by the pressurized steam. A variety of problems can be encountered in steamflooding; e.g. the steam tends to rise and override the formation; or the injected steam can "finger" through the formation

TABLE 1 - Properties of Principal Canadian Oil Sands and Heavy Oil Formations

		Athabasca	Cold Lake	Wabasca	Peace River	Lloydminster
Oil in Place	10^9 barrels	800	165	85	75	27
	10^9 m^3	127	26	13	12	4.3
Depth	feet	0-2000	1000-2000	250-1000	1000-2500	1000-3000
	m	0-610	305-610	75-305	305-760	305-915
Average Pay	feet	70	42	28	37	10-20
	m	21	13	8.5	11	3.1-6.1
Average Oil in Place	barrels/acre foot	1500	1240	1100	1150	2300
	m^3/m^3	0.193	0.160	0.142	0.148	0.296
Porosity	%	30-40	30-35	30-35	25-30	30
Gravity*	°API	7-8	10-12	6	8-9	12-23
	Specific	1.01-1.02	0.99-1.00	1.03	1.01	0.92-0.99
Reservoir Temperature	°C	10	12	10	12	22
Viscosity*	cp (mPa s)	2×10^6	100,000	5×10^6	100,000	500-4000

* at reservoir temperatures

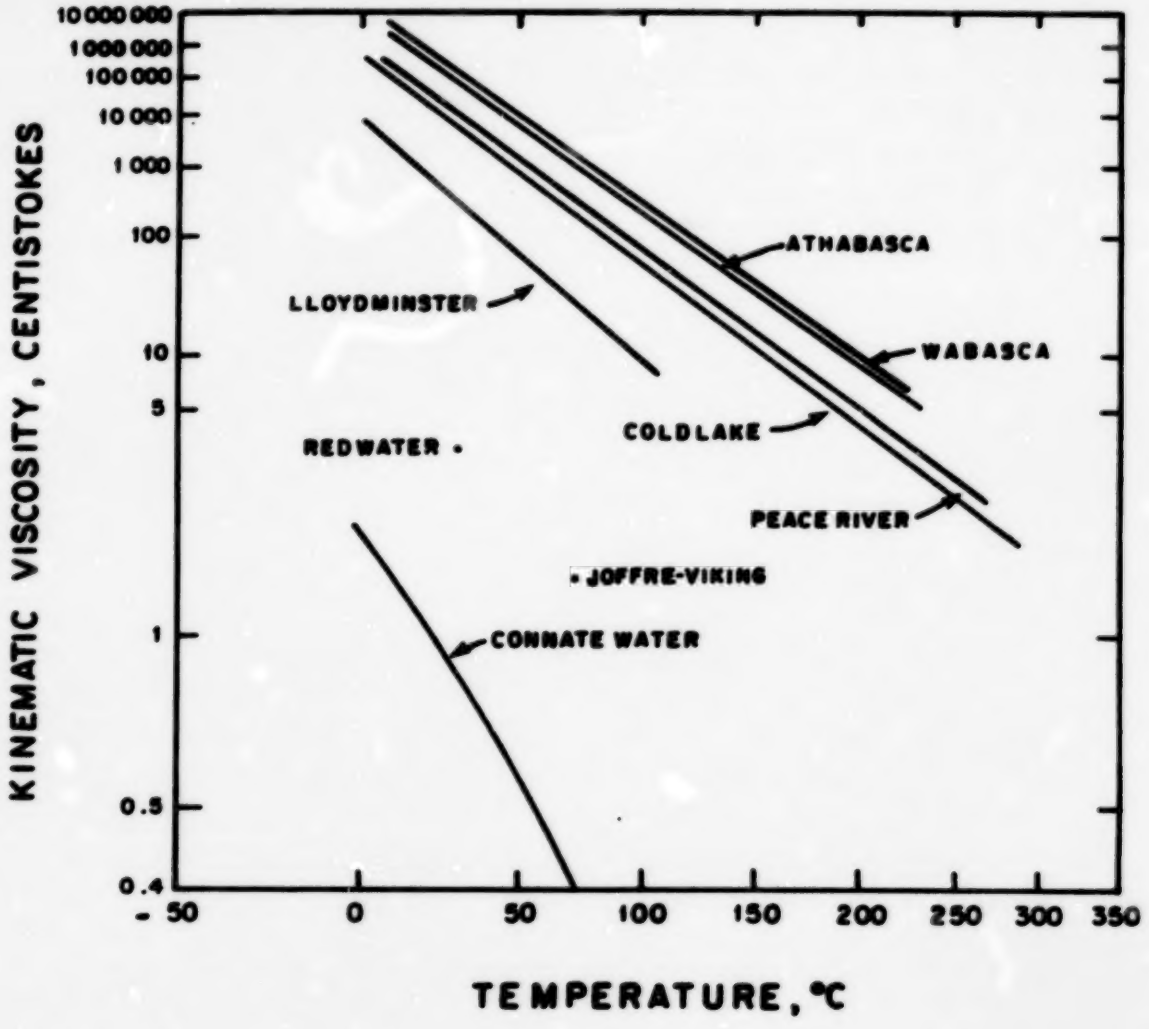

FIGURE 1: The Effect of Temperature on the Viscosity of Canadian Heavy Oil and Bitumens (1)

by-passing the main body of the reservoir. Either or both tendencies lead to poor areal sweep efficiency and low recovery.

For steam injection processes to work the reservoir must naturally possess, or it must be possible to create, some injectivity. The steam must be able to contact a significant proportion of the reservoir to reduce the viscosity of the bitumen so that flow becomes possible. In steamflooding there must also be communication between wells for the drive to work. In most circumstances in Canada, the oil sands have almost zero effective permeability at reservoir conditions. Since the connected void spaces tend to be filled with bitumen which is virtually immobile there can be no steam injection until flow channels are created. The most common method of accomplishing this is to fracture the reservoir by injecting steam at a pressure greater than the overburden pressure. This leads to the formation of channels for the steam and hot water to flow through.

In these and other in-situ processes the operations are complicated by the heterogeneities existing within the reservoir. The thickness of the oil sand deposit varies from one place to another; layers of clay and silt occur erratically; and the water and bitumen content often vary widely throughout the reservoir. These and other irregularities mean that one recovery approach will not be universally applicable. Clay and silt layers (called stringers) are of particular concern. First of all, their physical presence in a reservoir can act as a barrier to fluid flow and heat transfer which leads to lower bitumen recoveries than in areas without these layers. Secondly, fine sand and clay particles may be mobilized and, if transported through the formation, can lead to blockage of the pores thereby reducing recovery, or they may be carried to the producer well and add to the ever present "sanding" problem.

The first objective of this research is to develop a rapid, bench-scale technique to separate significant quantities of bitumen from a packed oil sands bed. Once such a technique is developed then a series of experiments can be designed with two main objectives. One is to assess the effects on bitumen recovery of varying the experimental conditions. The types of parameters which could be varied are temperature, pressure, adding gases with the steam, addition of surfactants to the water, steam quality and types of oil sand. The second is to develop a mechanism to describe the separation processes at a microscopic level. In addition to knowing how the reaction variables affect bitumen recovery it is important to know why they act as they do.

The experiments described in this report represent the first step towards developing the experimental techniques which will be used in subsequent research.

EXPERIMENTAL

The purpose of these preliminary experiments was to explore the general nature of the problem with a view to developing a technique which could be used to model cyclic steam stimulation. To develop a meaningful separation technique, three experimental arrangements were tried using a cylindrical displacement cell. Within each arrangement minor variations in experimental method occurred. Samples of oil sand were manually packed into these tubes using a rod with prongs on one end to compact the sand. The sand bed was packed by adding some of the sand, compacting it, adding more sand and so on. Glass beads were packed into the ends of the tubes to support the sand and also to buffer the oil sand from end effects (such as temperature drops). In the third arrangement the cell was designed to withstand high pressures.

Once the cell was packed, the steam or water (and nitrogen gas if it was being used) was pumped in and the heaters were turned on to bring the system up to temperature. In arrangements 1 and 2 the injected fluids were added over periods of about 6 hours. In arrangement 3 the water was pumped into the cell, heated and allowed to soak for several hours after which products were recovered causing the pressure to drop. In some experiments this cycle was repeated several times. The collected products of water and bitumen were analyzed for bitumen content following the procedure outlined in the Appendix.

ARRANGEMENT 1

The initial experimental arrangement is represented in Fig. 2. The apparatus consisted of a tubular cell which was packed with oil sands, a nitrogen supply and a collection vessel. The preliminary objective was to see whether or not simply heating the oil sands was sufficient to mobilize bitumen and lead to its collection by gravity drainage. Nitrogen was added to help carry along separated bitumen and also to ensure a non-oxidizing atmosphere.

The cell was heated using three separate Pyrotenax heaters to control the amount of heating to each zone of the cell. The temperature control system required three thermocouples and three temperature controllers. The temperature profile was determined by inserting a 1/8" O.D. thermocouple well into the centre of the cell and using a movable sheath thermocouple. It was found that a better temperature profile could be obtained if the bottom part of the cell and the lines running to the sample collection vessel were heated by a trace heater.

For some of the experiments a part of the heating was accomplished by steam injection. Steam was generated by pumping water from graduated burettes through coiled tubing wrapped with heating tape. The steam was admitted at the top of the cell both with and without concurrent flow of nitrogen.

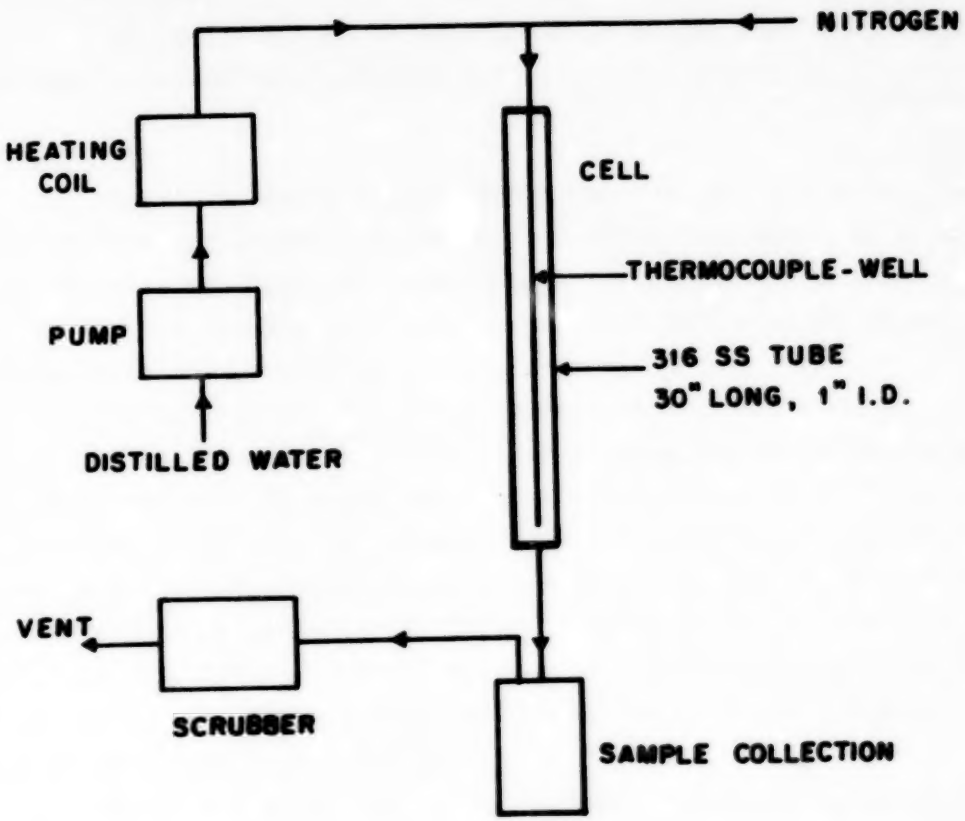

FIGURE 2: Initial Experimental Apparatus

ARRANGEMENT 2

A new cell was constructed as shown in Fig. 3. The "octupus" design allowed injection of steam and nitrogen from the top and at locations along the length of the cell. All of the experiments in Stages 1 and 2 were done with the cell open to atmospheric pressure.

ARRANGEMENT 3

In a third series of experiments the original tubular cell (with three staged heater-controllers) was set up in a bottom-feed mode. Water and steam were injected using a plunger type "Ruska" pump. The apparatus is shown schematically in Fig. 4. The products were recovered from the bottom except in the last experiment in which the products were recovered from the top.

The experimental conditions tested were markedly different from arrangements 1 and 2. In these experiments high temperatures and pressures were used. It was determined from the steam tables that a temperature of 245°C, in a closed container, should yield a steam pressure of 3.4 MPa (500 psi). The void volume in the packed cell (including void volume in the glass beads at the ends of the sand bed) was measured to be approximately 150 cm^3. About 50 cm^3 of water were added to the cell, heated to 245°C (3.4 MPa), and held at this temperature for several hours. At the end of this "soak" period the heat was shut off and the Ruska pump reversed to draw off the mobilized liquids.

In one experiment the entire cell was filled with water and heated to 245°C (3.4 MPa). After holding steady for several hours a valve was manually opened to release the pressure to less than 3.4 MPa. With this release of pressure some liquid products were recovered. This sequence was repeated several times and on three successive days.

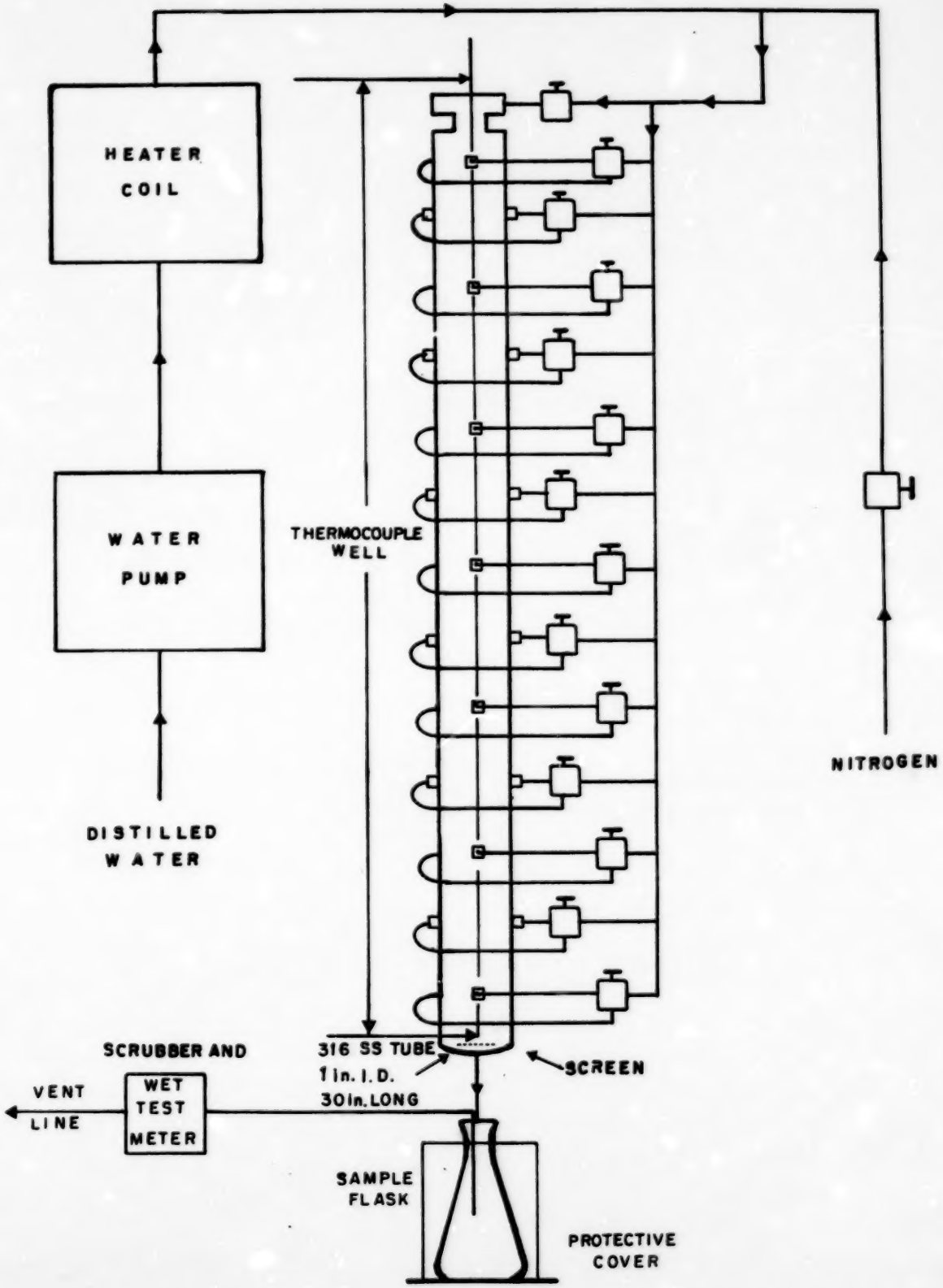

FIGURE 3: Second Bitumen Recovery Unit

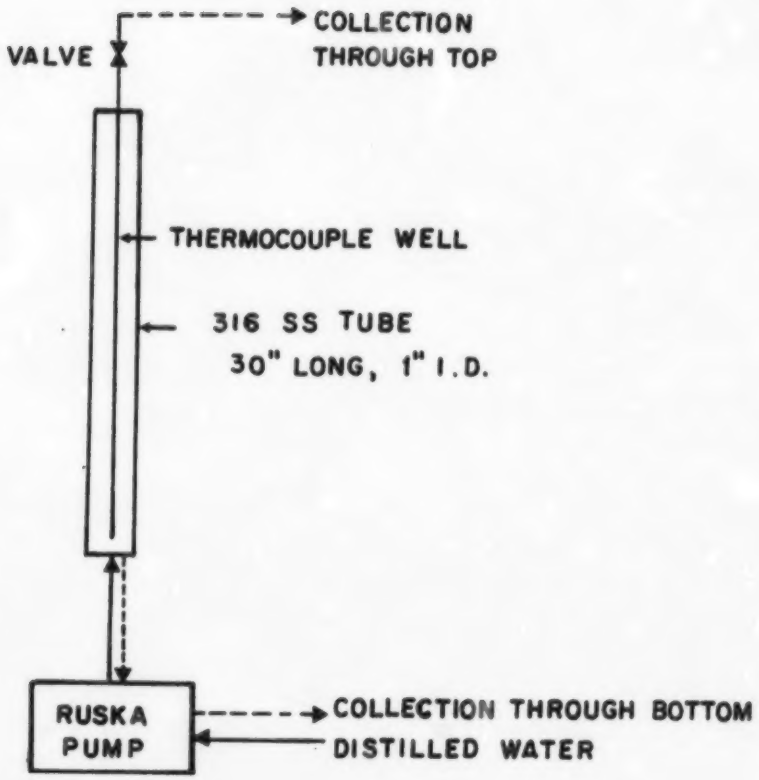

FIGURE 4: Third Bitumen Recovery Unit

RESULTS AND DISCUSSION

ARRANGEMENT 1

The fluids injected and the experimental results obtained using the first set-up are shown in Table 2. All the bitumen recoveries were small, but there was more recovery when just nitrogen was injected. This may have been due to the higher temperatures existing when nitrogen was injected alone compared to the temperatures when steam and nitrogen were injected together.

In one of the experiments in which just nitrogen was used the products recovered were 10.1 g of water and 1.7 g of oil (NOTE: Some additional water was likely lost as steam). The amount of oil sand used in this test was 513 g and had an approximate analysis as shown in Table 3. On this basis, 39% of the water contained in the sand was removed but only 2.6% of the bitumen was recovered, indicating that the use of heat alone tends to drive off the contained water but does not result in much bitumen recovery. Visual inspection of the sands afterwards showed a gradual colour progression from bottom to top indicating that a small amount of gravity drainage does occur but not enough to effect significant recovery. This experiment was repeated with recoveries of 31% of the contained water and 5.0% of the bitumen. As the temperature in these experiments was approximately 200°C, the viscosity of the bitumen would have been of the order of 10 cp.

When using steam injection from top to bottom, very little bitumen was recovered. Using steam in combination with electric heating, the temperature of the cell was held close to 100°C. At this temperature, the viscosity of the bitumen would still be several hundred centipoises. This lack of mobility may account for the low observed recoveries.

TABLE 2 - Bitumen Recoveries Using Nitrogen and Steam-Nitrogen*

Injected Fluids	Temperature (°C)	Wt % Bitumen Recovered
Steam-N_2	80-125	trace
Steam-N_2	80-100	trace
N_2	200	2.6
N_2	190	5.0

* at atmospheric pressure

TABLE 3 - Average Analysis of Athabasca Medium Grade Oil Sand*

Bitumen	12.0%
Water	5.1%
Solids	81.9%
Discrepancy	1.0%

* provided by the Alberta Research Council Oil Sands Sample Bank

ARRANGEMENT 2

Using the configuration shown in Fig. 3 hot water (and/or steam) and nitrogen were injected at different locations throughout the tube. The general method of operation was as follows: steam was passed from top to bottom for an hour or so to bring the cell and sand bed up to temperature; then the top valve was closed and the bottom steam valve opened. The side valves were then sequentially opened and closed progressing from the bottom to the top.

The results are shown in Table 4. The temperature noted for each experiment is the approximate temperature at which the cell was maintained using the three heating cables. The pressure was atmospheric throughout except when plugging occurred in which case some erratic (small) pressure increases were observed.

The results indicate that hot water ($T \leq 100°C$) is more effective for recovering bitumen than superheated steam ($T > 100°C$) is with the maximum recovery being about 18%. The relatively low recovery of bitumen (even using hot water) could be due to the following reasons:

(a) Since the water was being introduced from the top it flowed to the bottom due to gravitational forces. This could lead to channeling. The density of the sand bed pack was calculated to be about 1.4 to 1.7 g/cm^3, compared to an in place density of about 2 g/cm^3 for oil sands. The experimental sand pack would have an additional porosity of 15-30% as opposed to zero initial porosity in the ground. (NOTE: cited porosities of 30-35% for oil sands refer to the sand bed alone after mobilization of the bitumen and water). With this artificial porosity it is easy to imagine that channeling might occur.

(b) Since the temperature was of the order of 100°C the viscosity of the bitumen would still be quite high and the unfavourable mobility ratio would prevent the formation of an oil bank.* Nevertheless bitumen can be separated

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* The mobility ratio for the displacement of one fluid by another is defined as:

$$\frac{k_1 \mu_2}{k_2 \mu_1}$$

where k = relative permeability
μ = viscosity
1 = displacing phase
2 = displaced phase

If the mobility ratio is less than 1 then a relatively flat displacement front forms which leads to a good sweep efficiency. If the ratio is greater than 1 then the displacement process is less complete.

TABLE 4 - Bitumen Recoveries Using Hot Water and Steam

Temperature °C	Wt. of Oil Sand (g)	Percent Recovered
85	500.3	18.4
100	494.8	17.5
115	483.9	1.4
130	500.0	.1
145	506.5	2.5
160	496.0	.6

from sand by water at these temperatures as evidenced by the Clark hot water process. Obviously the recovery efficiency in a packed bed would be considerably less than that which is observed in the Clark process owing to the more restricted contact between oil sand and water.

(c) At 80-100°C the density of bitumen is less than that of water and so gravitational segregation tends to cause the bitumen to rise. On the other hand, the flow of water was from top to bottom so this liquid flow tended to force the bitumen downwards. These two forces opposed one another and bitumen recovery may have suffered.

(d) At temperatures above 100°C, it is possible that some of the oil sand is being heated in a dry environment which could drive off the contained water causing the sands to become dry. Once the sands are dried, separation of the bitumen and sand is very difficult.

ARRANGEMENT 3

In the first of these experiments, roughly 50 cm^3 of water was added to the cell. When the cell was heated to 245°C a pressure of 3.4 MPa (500 psi) resulted (consistent with the steam tables) and high temperature saturated water occupied the bottom part of the cell while saturated steam occupied the upper part. As long as the volume of water added is less than the void space, a pressure of 3.4 MPa will result (at 245°C) and the ratio of steam to water will depend upon the initial amount of water injection. The bitumen recoveries for these experiments, shown in Table 5, were all less than 3% of the initial bitumen-in-place.

In the final experiment, the cell was almost completely filled with water and heated to 245°C. After a couple of hours the pressure was released to slightly below 3.4 MPa by manually opening a valve at the top of the cell allowing water, steam and bitumen to flow out. The total bitumen recovered over the three days was 26% of the initial bitumen. The bitumen which was actually separated from the sand but not recovered, was found in the upper cap when the cell was dismantled and was added to the total. The overall recovery of bitumen then amounted to 37% of the total original bitumen. A recovery in this range is ideal as a starting point because there is ample room to detect both upward and downward shifts resulting from changes in the operating method.

TABLE 5 - Bitumen Recovery Using Steam Soaking and Pressure Cycling*

Water Initially Injected (cm^3)	Wt % Bitumen Recovered
50	3.2
50	1.5
50	2.0
150 (reactor filled)	37.0

* at 245°C (3.4 MPa)

CONCLUSION

It is possible to separate signficant quantities of bitumen from oil sand using a relatively simple experimental arrangement. Additional work is needed to make the test more representative of an in-situ steam stimulation and to refine the method of operation so that more reproducible results can be obtained. The next report in this series will look at in-situ recovery models in the literature, to assist in the development of a suitable experimental technique.

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APPENDIX

The bitumen and water recovered during a displacement run were analyzed for bitumen by the Dean Stark procedure. The bitumen content of a sample of oil sand can be determined by a variation of this method. Brief summaries of the procedures are listed below.

DEAN STARK OIL SAND ANALYSIS

1. Place 400 ml toluene in the round bottom flask.
2. Weigh extraction thimble to 0.01 g.
3. Weigh water collection bottle.
4. Weigh 120-140 g of tar sand into thimble.
5. Place thimble in a wire basket fixed to the distributor and suspend from the bottom of the still head. (The weighing and set-up should be done quickly to avoid loss of water from the sample).
6. Assemble apparatus as in Fig. 5.
7. Circulate cold water through condenser.
8. Turn on heating mantle and reflux for two hours.
9. During reflux period, drain water (bottom layer) from the side arm when necessary and filter through phase separating filter paper and transfer into the tared bottle. (Do not allow water to sit on phase separating filter paper for more than 30 seconds).
10. After reflux period, leave stopcock on side arm partially open and allow about 300 ml toluene to distill over into a 600 ml beaker.
11. Turn off heating mantle and allow to cool for about ½ hour.
12. Reweigh water bottle and determine weight of water.
13. Weigh aluminum dish and tray.
14. Remove thimble containing sand.
15. Quantitatively transfer the bottoms from the flask to the preweighed aluminum dish.
16. Place aluminum dish and the thimble in the oven and dry overnight at 90°C (about 15 hours).
17. Remove from oven and let cool for 15 minutes.
18. Weigh thimble and determine weight of solids.
19. Weigh aluminum dish and determine weight of bitumen.

DEAN STARK BITUMEN-IN-WATER ANALYSIS

1. Add 20 ml concentrated HCl to sample, shake and allow to stand overnight to break emulsion.
2. Decant off any free water.
3. Filter under water aspirator vacuum through a Buchner funnel using Whatman #54 filter paper.
4. Place 400 ml toluene in the round bottom flask.
5. Weigh water collection bottle.
6. Transfer filter paper and bitumen to a thimble and weigh.

Then steps 5-19 of the oil sand analysis method are performed.

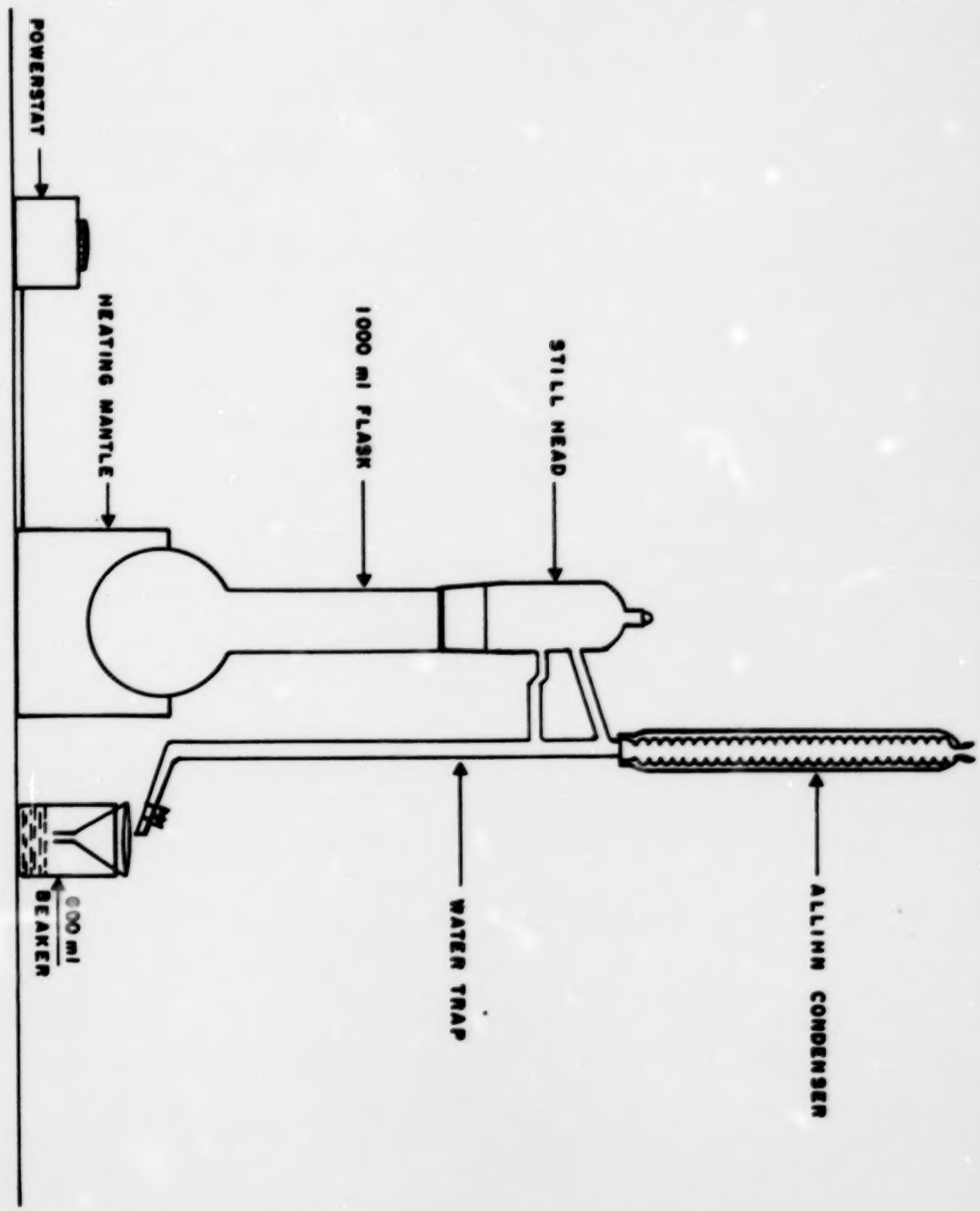

FIGURE 5: Apparatus Used in the Dean Stark Analysis

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